AD-A286 163

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CRREL

SPECIAL REPORT 94-21

Gravel Road Test Sections Insulated with Scrap Tire Chips

Construction and First Year's Results

Robert A. Eaton, Richard J. Roberts and Dana N. Humphrey August 1994

Abstract

A test project that uses tire chips as an insulating layer to limit frost penetration beneath a gravel-surfaced road is described. Tire chips, which are waste tires that have been cut into 2-in. pieces, are an attractive alternative to conventional insulation boards because they have moderate thermal resistance and are durable, free-draining and low cost. Furthermore, this application has the potential to make an important contribution to disposing of the more than 2 billion waste tires that are currently sitting in huge open piles across the U.S. The project was constructed in Richmond, Maine, in August 1992. It is 750 ft long, consisting of five sections with different thicknesses of tire chips and overlying soil cover and two control sections. Over 20,000 waste tires were used on this project. The primary goals were to determine the necessary thickness of tire chips to provide effective insulation and the minimum thickness of overlying soil cover needed to produce a stable riding surface. The thickness of the tire chip layers ranges from 6 to 12 in., while the thickness of the granular soil cover ranges from 12 to 24 in. The project is instrumented with thermocouples, resistivity gauges, groundwater monitoring wells and a weather station. In addition, the strength of the road surface is periodically measured with a heavy weight deflectometer. Results from the first year of service have shown that a 6-in. tire chip layer can reduce frost penetration by up to 25% and the gravel cover should be 12 to 18 in. thick to provide a stable riding surface.

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380-89a, *Standard Practice for Use of the International System of Units*, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

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U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

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August 1994

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

PREFACE

This report was prepared by Robert A. Eaton, Research Civil Engineer, and Richard J. Roberts, Civil Engineering Technician, of the U.S. Army Cold Regions Research and Engineering Laboratory, and Dana N. Humphrey, Associate Professor, Department of Civil Engineering, University of Maine, Orono, Maine. Funding for this study was provided by Office of the Chief of Engineers and a grant from the State of Maine, which paid for the construction.

The authors thank Nancy Churchill, Town Manager, and Richard LaChance, Road Commissioner, and the Town of Richmond, Maine, for volunteering a road in their town f he field trial test sections. Thanks are also given to Jimmy Hayes, President, and Bob Wieluns, Vice President, of Pine State Recycling in Nobleboro, Maine, for donating the tire chips used in this project. Mark Hardenberg and all other CRREL TRC personnel are sincerely thanked for editing, drafting and providing other services in publishing this report.

A short videotape summarizing this work is available from Robert Eaton, U.S. Army Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755–1290.

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
inch	25.4	millimeter
foot	0.3048	meter
mil	0.0000254	meter
$yard^3$	0.09144	$meter^3$
pound	0.4535924	kilogram
pound/$foot^3$	16.01846	kilogram/$meter^3$
pound/$yard^3$	0.5932764	kilogram/$meter^3$
degrees Fahrenheit	$t_C = (t_F - 32)/1.8$	degrees Celsius

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Gravel Road Test Sections Insulated with Scrap Tire Chips
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ROBERT A. EATON, RICHARD J. ROBERTS AND DANA N. HUMPHREY

INTRODUCTION

The U.S. has a problem disposing of scrap rubber tires. CRREL began to address this issue in 1989, working on research project H-204 for the National Strategic Highway Research Program (SHRP). This research resulted in a new asphalt pavement material containing pieces of scrap rubber called Chunk Rubber Asphalt Concrete, which prevents ice from bonding to the pavement surface, making snow and ice removal easier without the use of chemicals and providing a skid-resistant surface under black ice or wet conditions (Eaton et al. 1990).

Development of construction and engineering specifications for the use of this rubber aggregate material continues. However, CRREL began exploring the advantages of using rubber in other aspects of roadway construction. For example, advantages are reductions in frost penetration into underlying subgrade soils and in frost heave. Reducing frost penetration allows the engineer to reduce the thickness of the base course (usually in frost-affected areas, the thickness of the pavement structure is controlled by the depth of frost penetration, *not* by load). In CRREL's area, 1 in. of Styrofoam board insulation in the pavement structure is equivalent to 12 in. of gravel—if a local street requires 48 in. of base for frost protection, but only 24 in. for load support, the structure could be constructed with 2 in. of insulation covered by 24 in. of gravel. The savings would be *x* yards of gravel minus the insulation cost. One objective of this study is to determine the effectiveness of cheap scrap rubber chips vs. expensive extruded Styrofoam board insulation

Another objective here is to see how much gravel cover is necessary above the rubber chips to minimize or overcome any weakness of the rubber chips. Year-round deflection tests are being conducted to compare surface deflections and to determine the equivalencies of the different layers of materials. It could turn out that more gravel is required to support loads than is cost-effective. If this is so, that is what this study will report.

The approach used here was to utilize tire chips as an insulating layer. The benefit of disposing of large amounts of tires is additional.

Prior CRREL work has shown that insulation reduces freezing and the subsequent loss of strength upon thawing of frost-susceptible subgrade soils beneath roads. But, it is seldom used for unpaved roads because of the high cost of expanded and extruded polystyrene boards. An attractive alternative may be the use of tire chips as the insulation layer. Tire chips are made by chopping waste tires into pieces ranging in size from less than 2 to more than 12 in. Tire chips are durable, free-draining and have an insulating value. Moreover, they are available at a reasonable price in many parts of the U.S., and using tire chips as an insulating layer could make an important contribution to the problem of waste tire disposal.

Town officials in Richmond, Maine, learned of this technique and obtained a grant to use this approach to solve an annual maintenance problem on one of their roads. The town hired Professor D.N. Humphrey of the University of Maine (and co-author of this report) to design a test road, and he contacted CRREL to allow us to participate in monitoring the performance of the test sections. CRREL's objectives were to monitor 1) the thermal performance of the rubber layers using temperature and resistivity sensors, and 2) the load-bearing capacity using surface deflection tests that will be conducted year-round. In addition, frost heave, traffic count and weather data will be collected, and groundwater changes will be observed.

The 750-ft project consists of five sections with different thicknesses of tire chips and overlying granular material. In one test section, the tire chip layer is enclosed by a geotextile. The thicknesses of the tire chip layers range from 6 to 12 in. and the granular soil cover ranges from 12 to 24 in. In addition, in one of the control sections, no tire chips are used.

Substantial long-term engineering and environmental benefits could result. The need for high-quality gravel could be reduced in areas where it is not readily available. If we can show that scrap rubber tire chips are usable in this manner, with acceptable environmental implications, large volumes of tires could be used. In this test road, which is 600 ft long and 20 ft wide, 20,000 scrap tires were used. The 1.2 million scrap tires generated in Maine each year could be used up in the construction of only 6 miles of road.

SITE DESCRIPTION

The test site is located on Dingley Road in Richmond, Maine (Fig. 1), which is a dead-end, gravel-surfaced road serving 29 residences, whose main traffic is cars, light trucks and school buses. However, one day a month, 10 to 40 fully loaded double- and triple-axle dump trucks haul treated sewage sludge to farms at the end of the road. Residents report that the road surface becomes severely rutted during the annual spring melt.

The road follows the northeast shoulder of a broad, flat ridge that runs in a northwest–southeast direction. The test site is bordered by mixed deciduous and conifer woods. During the summer and fall, there were no standing water or wet areas near the test site; however, during the spring melt, the generally flat topography leads to poor drainage and areas of standing water.

The ditches on either side of the existing road ranged from 12 in. deep at the northwest end of the test site to 36 in. deep in the southeast end. They

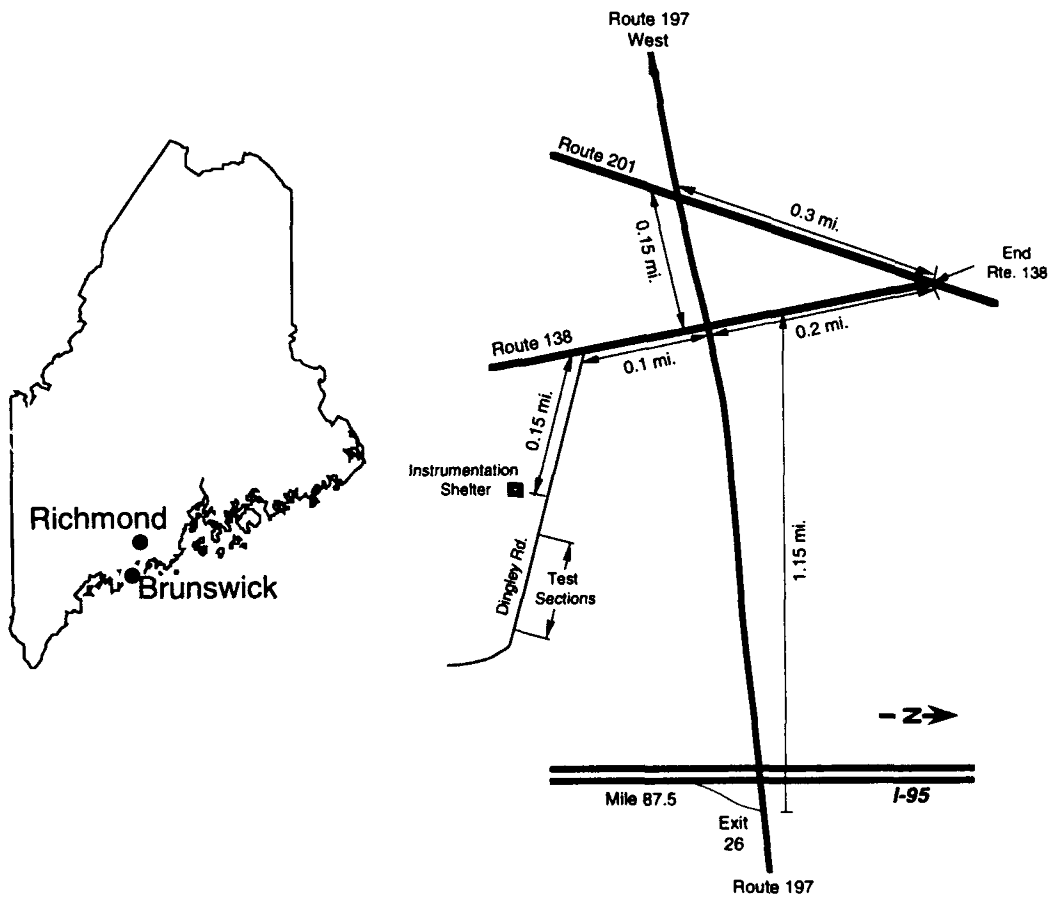

Figure 1. Location of field test site.

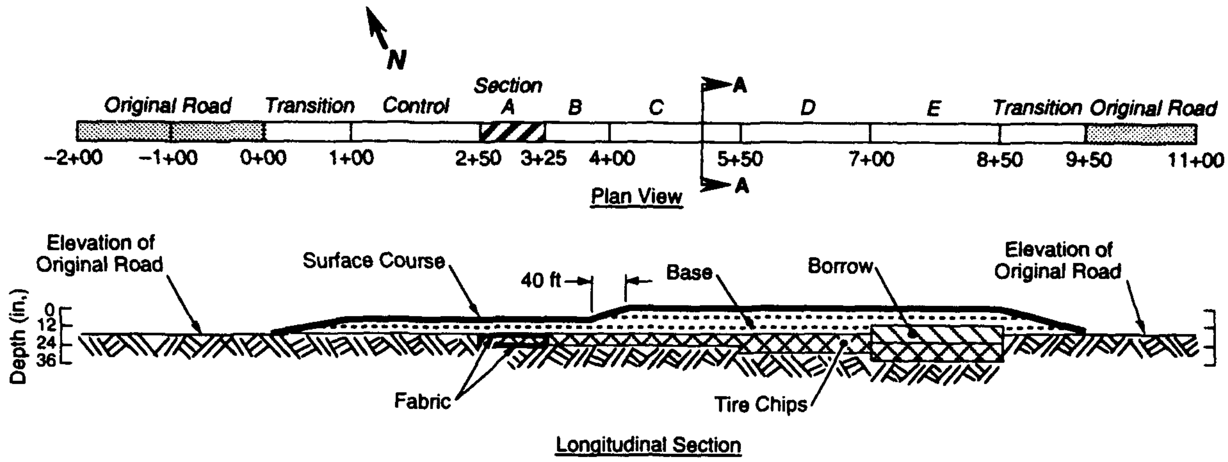

Figure 2. Plan and longitudinal views of test sections (cross section A-A is Fig. 3).

drain with a gentle slope to the southeast. Water in the ditch on the southwest side of the road flows 900 ft, nearly the entire length of the project, to its only outlet, a culvert at the southeast end of the site. Water in the ditch on the northeast side flows into adjoining woods at roughly the midpoint of the project and at the southwest end of the project.

In most areas, the existing road was surfaced with more than 18 in. of clean sandy gravel and gravely sand. The underlying native soils ranged from gray silty clay to gray-brown silty gravely sand. These soil types are highly frost-susceptible. Probing with a 6-in.-diameter power auger, we hit refusal at depths ranging from 9 to 18 ft. The general geology of the area suggests that refusal was caused either by glacial till with boulders or bedrock. The water table in the summer and fall is 6.5 to 10 ft below the ground surface; however, during the spring melt, the water table is near the surface.

TEST SITE CONFIGURATION

General layout

We divided the 950-ft-long test site into five tire chip test sections—A and B, each 75 ft long, and C, D and E, each 150 ft long—a 150-ft-long control section with no rubber chips and two 100-ft transition sections as shown in the plan and longitudinal views in Figure 2. We used two thicknesses of tire chips to investigate the insulating effect of this material, and we placed three thicknesses of granular soil over the tire chips to determine the thickness needed to stabilize the surface. The entire section was topped with a 4-in. granular surface course to provide a smooth, low-maintenance riding surface. A typical cross section is shown in Figure 3.

Before the tire chips were placed, the existing road surface of 6 to 18 in. of material was excavated, which in most cases extended down to the in-situ

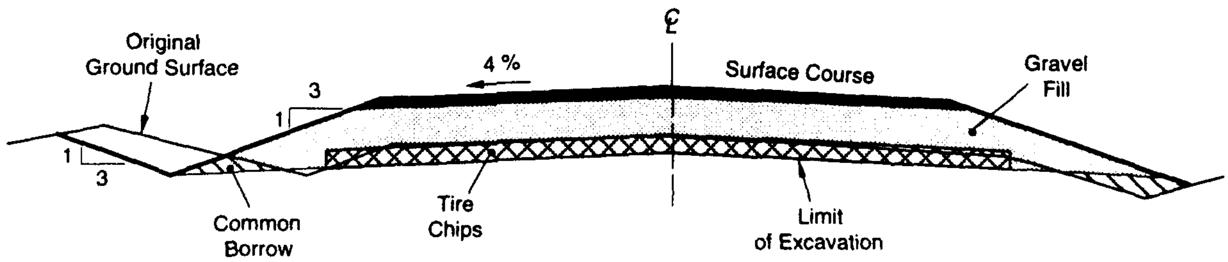

Figure 3. Typical cross section.

soil. This was done to keep the final grade of the test sections from being too far above the surrounding terrain. The excavated surface was higher than the existing ditches and sloped toward both ditches to enhance drainage. A minimum of 24 in. of gravel cover was used at the outer edge of the tire chip course on the 3:1 side slopes (Fig. 3).

One control section, that consisting of new granular soil, was placed directly on the excavated surface. In addition, an adjacent section of the original road is also being monitored. The 100-ft-long transitions at each end provide a gradual change in grade from the original road surface to the new grade of the test sections. Flake calcium chloride was applied to the road surface at a rate of 0.75 lb/yd^2 to make a water-tight surface for dust control and to reduce loss of fines.

Materials

The tire chips were smaller than 2 in. and were made from a mixture of steel- and glass-belted tires. They were irregularly shaped and many had steel fibers protruding from their cut edges (Fig. 4). A typical gradation is shown in Figure 5. The tire chips had a uniform gradation with most of the material retained on the no. 4 U.S. standard sieve; however, a few pieces were larger than the 2-in. nominal maximum size. The tire chips were do-

Figure 4. Tire chips.

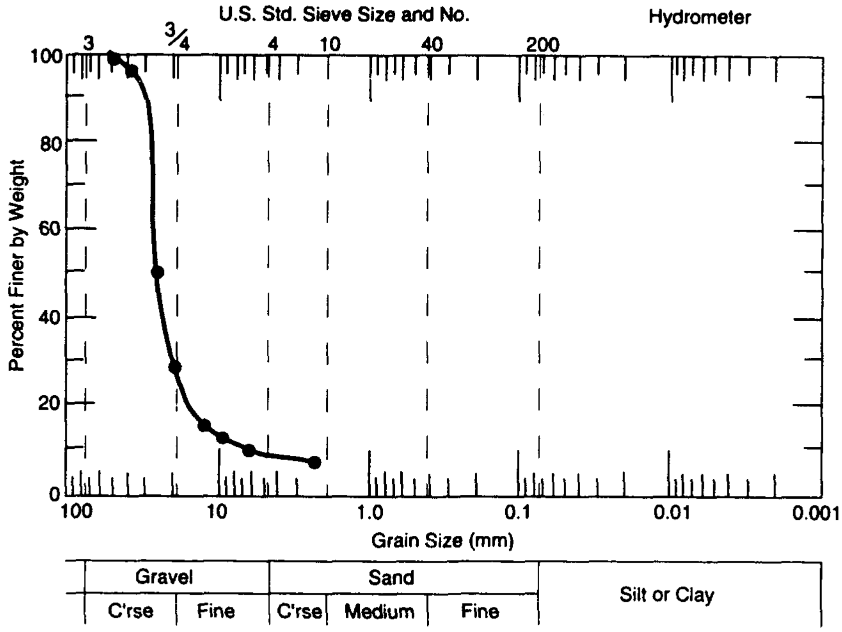

Figure 5. Gradation of tire chips.

nated by Pine State Recycling of Nobleboro, Maine. About 20,000 tires were used in this small project, which clearly shows the potential of this application to use large quantities of waste tires.

The gravel fill used over the tire chips was a well-graded mixture of sand and gravel, having maximum particle size of 6 in., with less than 5% passing the no. 200 U.S. standard sieve. The specified gradation is shown in Table 1, and a typical gradation of the gravel fill is shown in Figure 6. The gravel fill was obtained from an outwash deposit, and most of the particles were rounded to subrounded in shape.

The surface course was a well-graded mixture of sand and gravel, with a specified gradation shown in Table 1. A maximum particle size of 1 in. was specified to provide a smooth riding surface that is easy to regrade. The higher percentage of fines is needed to bind the particles together and prevent raveling during dry periods. A typical gradation of the surface course is shown in Figure 6. The soil used for the surface course was the same as that used for the gravel fill except for material larger than 1 in., which had been screened out.

Common borrow was used as part of the soil cover over the tire chips in test section E to reduce the quantity of imported granular fill. The common borrow was salvaged from granular soil excavated from the original road surface. Typical gradations of the common borrow are shown in Figure 6, indicating that it is a gravely sand with a trace of silt.

Description of tire chip test sections and control section

As mentioned earlier, test sections A and B are each 75 ft long. In both sections, 6 in. of the original road surface was removed before 6 in. of tire chips, covered with 8 in. of gravel fill and the 4-in.-thick surface course, was placed. The sections were identical except that the tire chips in section A were completely enveloped in a woven geotextile (Amoco 2000–2). One purpose of these sections is to evaluate the need for a geotextile filter to minimize infiltration of the underlying and overlying soils into the tire chip layer.

Table 1. Specified gradation for gravel fill and surface courses (percent passing).

Sieve designation	*Gravel fill*	*Surface course*
6 in.	100	—
1 in.	—	95–100
No. 4	25–70	40–65
No. 10	—	10–45
No. 40	0–30	—
No. 200	0–7	7–13

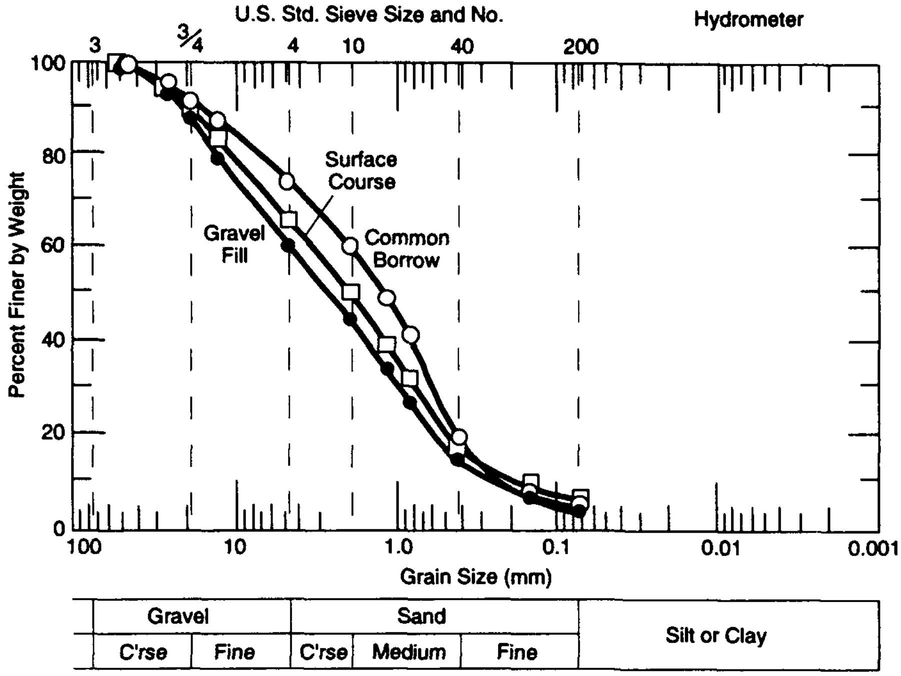

Figure 6. Gradations of gravel fill, surface course and common borrow.

Test section C is 150 ft long, and the depth of excavation and the thickness of the tire chip layer are the same as in sections A and B. However, the thickness of the overlying gravel fill was increased to 14 in., while the thickness of the surface course was maintained at 4 in.

Test section D is also 150 ft long. In this section the depth of excavation of the existing road was increased to 12 in. and the thickness of the tire chip course was increased to 12 in. As with section C, the tire chips were covered with 14 in. of gravel fill topped with the 4-in.-thick surface course.

In the 150-ft test section E, the depth of excavation was increased to 18 in., but the thickness of the tire chip course was maintained at 12 in. The soil cover consisted of 12 in. of common borrow overlaid by 8 in. of gravel fill and the 4-in.-thick surface course.

The control section consisted of 8 in. of gravel fill placed directly on the original road surface. The gravel fill was topped with the 4–in.-thick surface course.

The depth of excavation and the thickness of each course in all sections are summarized in Table 2 and shown in the longitudinal section in Figure 2.

CONSTRUCTION

The test sections were constructed from 24 August through 2 September 1992, when the weather was warm and sunny. It was necessary to maintain one open lane at all times for local traffic. Furthermore, cars were not allowed to drive directly on the tire chips because the protruding steel fibers

Table 2. Summary of test section configurations.

Section	Depth of excavation (in.)	Thickness of layer (in .) Tire chips	Common borrow	Gravel fill	Surface course
Control	—	—	—	8	4
A	6	6	—	8	4
B	6	6	—	8	4
C	6	6	—	14	4
D	12	12	—	14	4
E	18	12	12	8	4

Figure 7. Unloading tire chips from the semi-trailer and spreading them with the small bulldozer.

could puncture their relatively thin tires. For these reasons, the contractor constructed the northwest-bound lane first. Then, when sufficient gravel cover had been placed over the tire chips, the traffic was diverted to this lane and the southeast-bound lane was constructed.

The first step was to excavate the northwest-bound lane of the existing road down to the desired starting grade. This was done by a wheel-mounted hydraulic excavator. Excavated material was hauled away by 15-yd^3-capacity dump trucks. Some of this material was stockpiled near the site for later use as common borrow, and the remainder was removed. The grade was smoothed by a small bulldozer and given the specified 4% slope toward the ditch. The exposed grade was then compacted with four passes of a vibratory, smooth-drum roller with a static weight of 20 tons.

The tire chips were hauled to the site in a 40-ft-long, self-unloading semi-trailer that could haul 22 tons in a single load. Initially, the tire chips were unloaded directly on the prepared subgrade and then spread to the desired thickness with the small bulldozer (Fig. 7). The bulldozer attempted to achieve the specified ±1/2 in. grade.

The tire chips were compacted with six passes of the roller (Fig. 8). As we watched, the first pass would compact a 12-in.-thick layer of tire chips by 1/2 to 1 in. Compaction on subsequent passes was too small to see. These observations convinced us that vibratory compaction equipment might be more effective.

One problem was encountered during unloading, spreading and compacting the tire chips: The outside edge of the tire chip layer could not be kept within the desired offset from the centerline. When the semi-trailer unloaded chips, a significant quantity would spill beyond the offset; in addition, spreading and compacting moved them laterally. The end result was that the tire chips were 1 to 3 ft beyond the desired offset and needed to be removed with an excavator.

The underlying cause of this problem was that the contractor was restricted to working on only one-half of the road at a time, which was only a 10- to 13-ft lane. Had it been possible to close the road to local traffic and work on the full width, this would not have been a problem. As a partial solution during the later stages of the project, the contractor unloaded the semi-trailer in a parking area near the site and then reloaded the tire chips into 15-yd^3-capacity dump trucks. When the dump trucks were unloaded, significantly fewer chips spilled outside the offset.

After the chips were placed, they were covered with the specified thickness of gravel fill or, in section E, with common borrow followed by gravel fill (Table 2). The gravel cover and common bor-

Figure 8. Compacting the tire chips with the vibratory roller.

row were hauled to the site in 15-yd^3-capacity dump trucks, spread in a 12-in. maximum thickness lift by the small bulldozer, and then compacted with six passes of the roller.

Modified proctor compaction tests were performed on representative samples of the gravel fill and common borrow. The optimum water contents and maximum dry densities are summarized in Table 3. During construction, three in-place density tests were conducted in the gravel fill and one in the common borrow (Table 4). The water contents were 2 to 3 percentage points drier than optimum and the relative compactions were rather low. The low water contents were undoubtedly a contributing factor in the low compacted densities. Using a vibratory compactor to compact granular soil placed on the compressible tire chips also may be important.

Table 3. Modified proctor compaction results.

Material	*Optimum water content (%)*	*Maximum dry density (lb/ft^3)*
Gravel fill	6.0	138.5
Common borrow	6.0	137.3

Finally, the 4-in.-thick surface course was placed on the gravel fill. It was hauled, spread and compacted in a manner similar to that used for the gravel fill, except that only four passes were made by the roller. A small road grader did the final shaping. The completed surface was treated with flake calcium chloride.

The complete construction specifications for the project are given by Humphrey (1992). Appendix A is a selection of construction photos.

MONITORING PROGRAM

An extensive monitoring system was put in place to evaluate the thermal behavior, road sur-

Table 4. In-place density test results.

Material	*In-place water content (%)*	*In-place dry density (lb/ft^3)*	*Relative compaction (%)*
Gravel fill	4.2	120.4	87.7
Gravel fill	3.3	112.9	82.3
Gravel fill	3.0	120.4	87.7
Common borrow	4.1	106.7	77.7

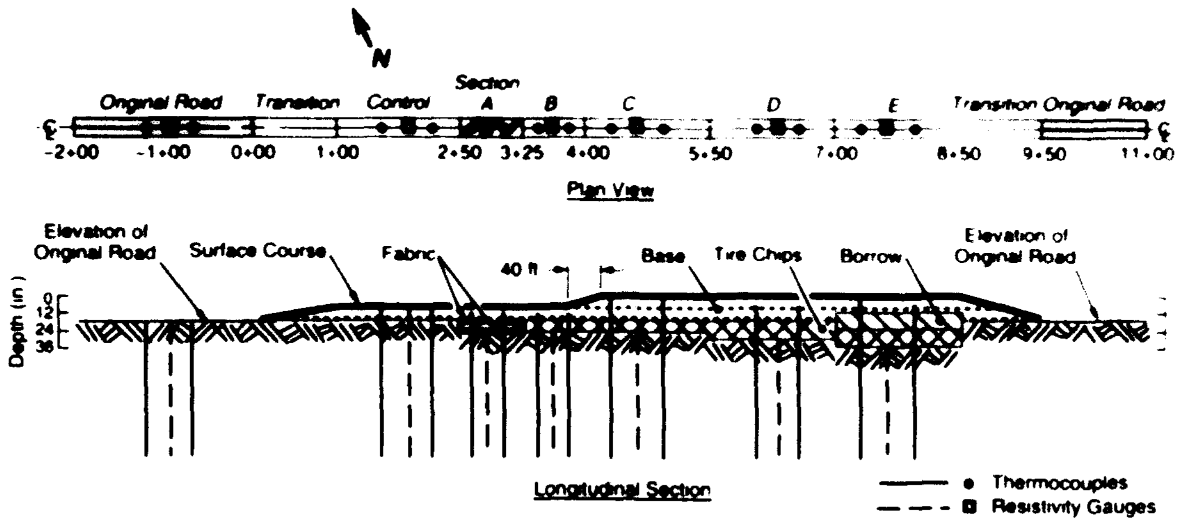

Figure 9. Location of thermocouples and resistivity gauges.

face support characteristics and groundwater quality of the project. The following instrumentation was installed: vertical strings of thermocouples at two locations in each of the five tire chip test sections, the control section and a section of the original road; resistivity gauges to monitor the location of the freezing front in each test section, the control section and the original road; six groundwater monitoring wells; and two frost-free bench marks. The thermocouples and resistivity gauges can be read by telephone from CRREL. The locations of the thermocouples and resistivity gauges are shown in plan and cross section in Figure 9, while the locations of groundwater monitoring wells, benchmarks and instrument readouts are shown in Figure 10. In addition, road surface deflections are measured with a heavy-weight deflectometer at several locations in each section, the road surface is surveyed to measure any frost heave and the condition of the road surface is monitored visually. The monitoring program will continue for 3 to 5 years. Details are discussed below.

Thermocouples and resistivity gauges

Two vertical strings of thermocouples are installed in each test section, the control section and the adjacent original, undisturbed roadway. Each string consists of twelve 20-gauge copper constantan thermocouples, whose spacings vary from 3 in. near the road surface to 12 in. at greater depths. The deepest thermocouple is typically about 6 ft below the road surface. An installation in a typical section (section C) is shown in Figure 11. To maintain the desired spacing, the thermocouples were mounted on a 1-in. diameter wooden dowel and installed in a 5-in.-diameter hole drilled with a trailer-mounted power auger. After placing the string, we backfilled the hole with native soil that was tamped in place with a hand tamper. The portion of a thermocouple string that will extend through the tire chip layer is shown in Figure 12.

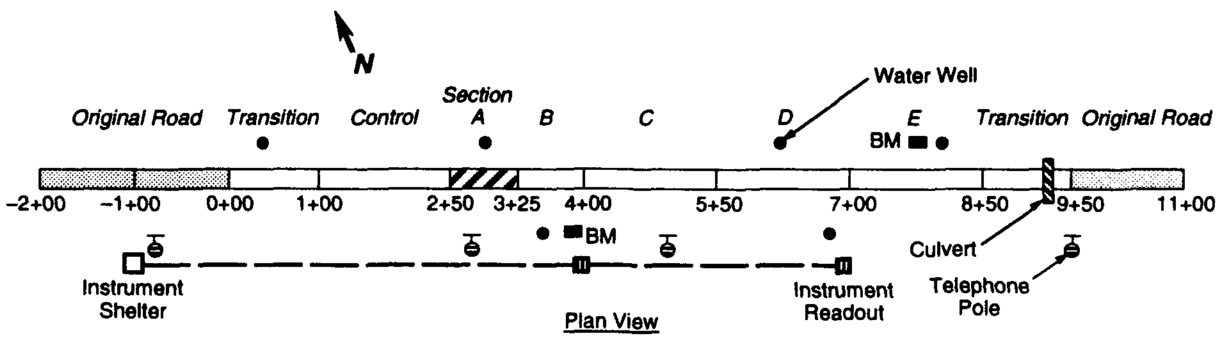

Figure 10. Location of groundwater monitoring wells, benchmarks and instrument readouts.

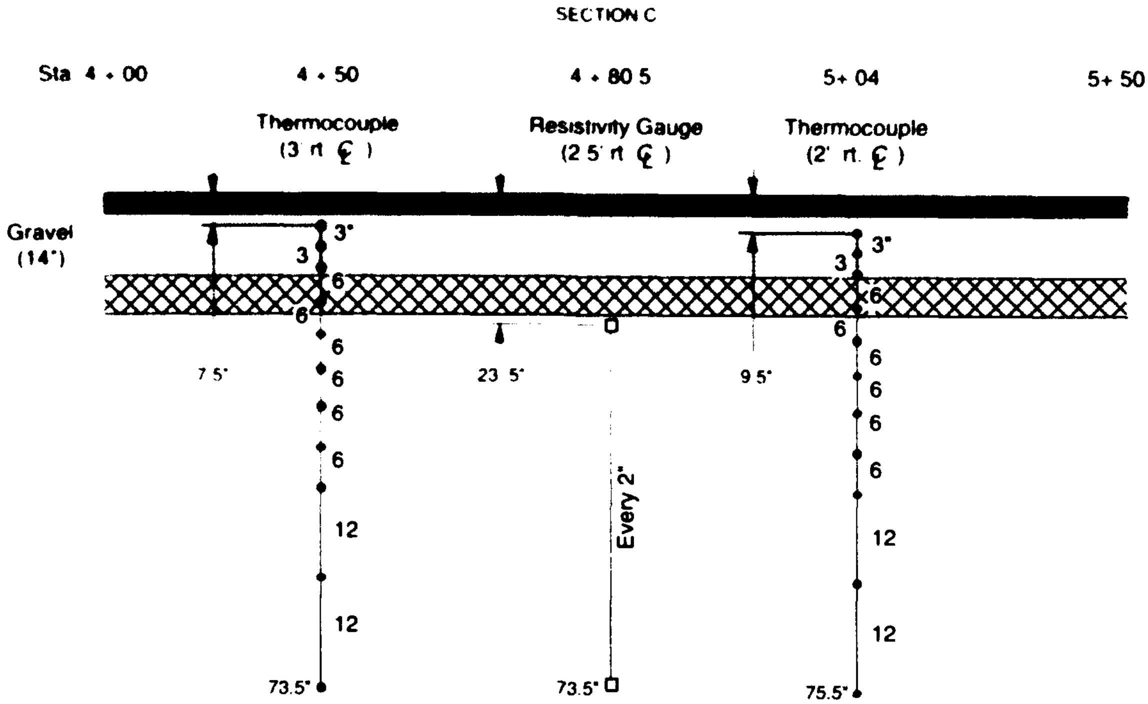

Figure 11. Longitudinal centerline cross section showing thermocouples and resistivity gauges in section C.

The electrical resistivity gauges consist of 1-in.-diameter copper rings spaced 2 in. apart on an epoxy filled core. The electrical resistance of the soil between adjacent rings is measured to determine if the soil is thawed or frozen (the reading for frozen soil is much higher than for thawed soil). This allows us to monitor the location of the freezing front and, during the spring, the thawing front. The resistivity gauges were 4 ft long. The top of the gauge was typically even with the bottom of the tire chip layer. The installation technique was the same as for the thermocouples (Fig. 12).

The actual depths and elevations of both the thermocouples and resistivity gauges are shown in Appendix B.

The wires from the thermocouples and resistivity gauges were placed in trenches leading to one of two instrument readout boxes. The readout boxes were in turn connected to a modem in an instrument shelter that permits the readings to be transmitted directly to CRREL. The location of the readout boxes and instrument shelter are shown in Figure 10. A thermocouple on the side of the instrument shelter records the air temperature.

One thermocouple string per section and the resistivity gauges are being read manually by five senior students at the Richmond High School under the direction of the physics teacher. Results are mailed to CRREL for correlation with the automatically recorded data. The students are also monitoring ground freezing behind the school under an instrumented, snow-covered area and an area shoveled free of snow to study the effectiveness of snow as an insulating material.

Heavyweight deflectometer measurements

The surface deflections of the road are measured with a Dynatest Heavyweight Deflectometer (HWD) at two to four locations in each tire chip section, the control section and on the original road. The HWD has a 4400-lb weight that is dropped onto an 18-in. diameter plate from varying heights. The resulting deflection of the plate and the deflection of the road surface at several distances away from the plate are measured. These measurements can be related to the support characteristics of the underlying material.

Appendix C contains the HWD test points.

Surface condition survey

The surface condition of the test and control sections will be rated periodically using a procedure for unsurfaced roads developed by Eaton et al. (1987). The procedure measures the following seven road distresses: improper cross section, inadequate roadside drainage, corrugations, dust, potholes, ruts and loose aggregate. The result of the procedure is a numerical Unsurfaced Road

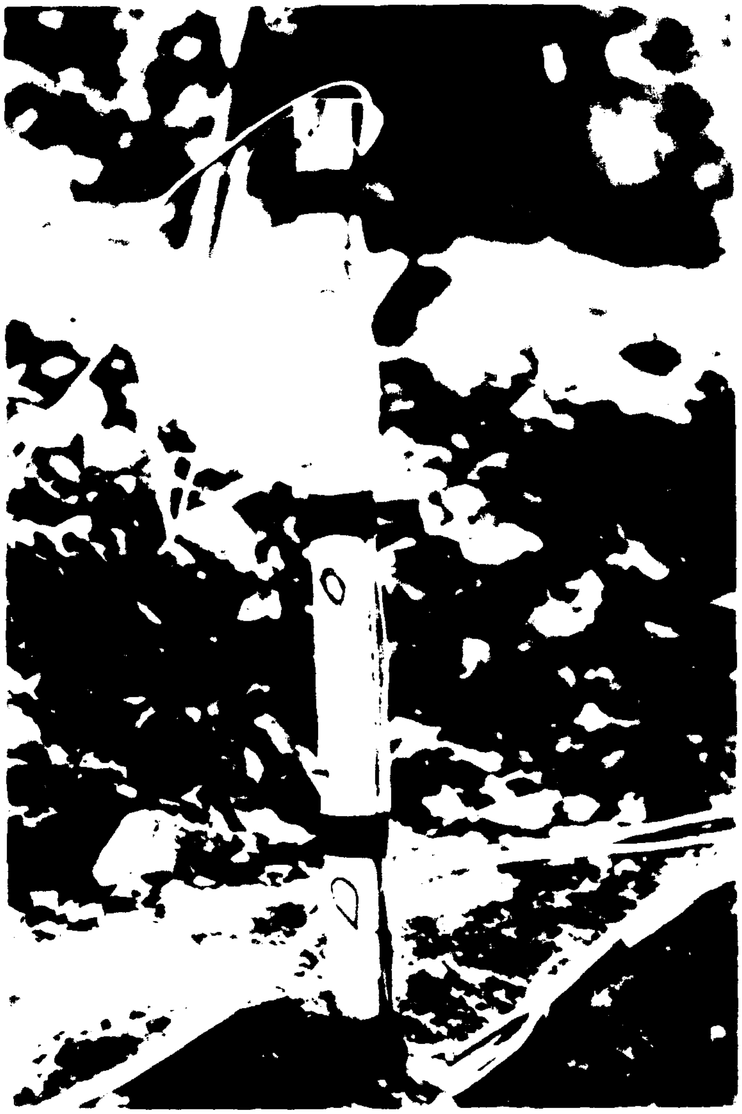

Figure 12. Portion of a thermocouple string that will extend through the tire chip layer.

Condition Index (URCI) and rating, ranging from excellent to failed.

Frost heave survey

The heave of the road surface will be measured several times during the winter with a level survey. The two frost-free benchmarks were installed to provide stable reference points for this survey. The frost heave of the different sections are compared. All survey points are given in Appendix D.

Groundwater wells

Groundwater monitoring wells were installed at six locations shown in Figures 10 and 13, so that water quality samples could be taken and the elevation of the groundwater table could be measured. The wells are 2-in.-diameter schedule-40 PVC pipe; a cap was glued to the bottom of the pipe and then a hacksaw was used to cut slots in the cap and bottom 2 ft of the pipe. The pipe was placed in a 5-in. diameter hole drilled with a trailer-mounted power auger and the slotted lower portion was surrounded with concrete sand. Then, a 1.5-ft thickness of bentonite balls was placed to form an impermeable seal to prevent surface water from reaching the slotted tip. The remainder of the hole was backfilled with native soil. Appendix E describes the wells.

One well is adjacent to the control section to provide background readings of water quality.

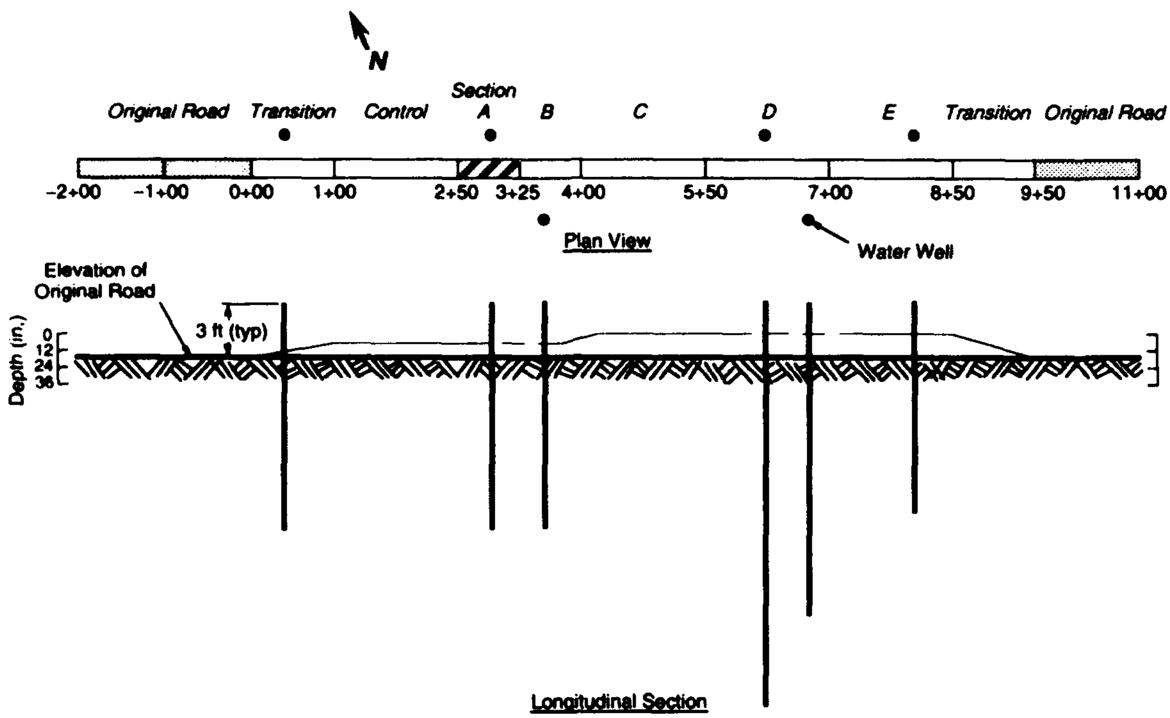

Figure 13. Water well locations.

The remaining five wells are adjacent to the tire chip test sections.

FIRST WINTER'S RESULTS

Freezing index

The freezing index at Brunswick Naval Air Station was determined to be 933 °F-days, following procedures in Gilman (1964). Measurements of the air temperature taken on the shaded west side of the instrument shelter from 18 November 1992 to 31 March 1993 gave a freezing index of 1084 °F-days. Temperatures are an average of 2.5°F lower at the Richmond site, so 44 additional °F-days were added, resulting in a freezing index of 1128 °F-days. The 1992–93 winter was slightly warmer than the "normal" design freezing index for the Richmond, Maine, test site of 1275 °F-days, which is based on the 3 coldest years in 30.

General observations

The performance of the test sections has been excellent, the only exception being some temporary distress noted in the first month after construction in sections A and B (12 in. of soil over 6 in. of tire chips). These sections became rutted after fully loaded dump trucks drove over them repeatedly, but in the following months, the same level of dump truck traffic produced little rutting. Apparently, these sections became stronger through time, possibly because precipitation increased the water content of the gravel cover, bringing it closer to optimum and allowing traffic to compact it, or perhaps the tire chip layer was further compacted by the traffic.

In sections A and B, elastic deflection of the road surface could be seen when a school bus passed, but not in the remaining sections. In addition, sections A and B had thin cracks in the compacted gravel where the wheel paths formed, but these cracks were not evident in the remaining sections.

Throughout the winter and the spring thaw, all tire chip sections, and the control section, provided stable riding surfaces. In contrast, the original road became severely rutted and almost impassable to two-wheel drive vehicles.

Frost penetration

Table 5 shows the maximum frost penetration values, as measured with the copper constantan thermocouples at 0400 hours each day, which were used for data analysis. The maximum depth of frost penetration in the original road and control section was 60 and 51 in. respectively. In contrast,

Table 5. Maximum frost penetration (in.).

Original road	*Control*	*Section A*	*Section B*	*Section C*	*Section D*	*Section E*
60	51	36	35	43	38	39

the maximum depth of frost penetration in the five tire chip sections was 35 to 43 in., clearly showing their beneficial effect.

Figure 14 shows the maximum depth of frost penetration in each section in relation to the tire chip layer. Sections A and B had similar maximum depths of frost penetration, as would be expected. Section C had the deepest frost penetration. In sections A, B and C, which all had 6 in. of tire chips, the frost penetrations below the bottom of the tire chip layer were all about the same—17 to 18 in.

Figure 15 shows the depth of frost penetration vs. date in sections A and B and the controls. The frost rapidly penetrated to 24 in. in all sections. However, after this initial period, the rate of frost penetration in the tire chip sections was less than that below the control section and the original road, and there was no further frost penetration in the tire chip sections after early February. In the control section and the original road, frost continued to penetrate into March.

Examining the temperature profile vs. depth near the end of the freezing season (16 March) also shows the effectiveness of the tire chips (Fig. 16).

Frost heave

Level surveys were conducted through the winter using the frost-free benchmarks at stations 3+85.5 and 8+27.5. The baseline survey was made on 30 March 1993, after thaw and before the road was graded or reshaped, and the maximum frost heave survey was made on 24 February 1993 at the time of maximum frost penetration.

Table 6 lists the maximum frost heave of the sections using the average centerline elevations for the dates described and Figure 17 shows the centerline maximum frost heave.

Groundwater elevations

Table 7 shows the groundwater levels that were measured in the six piezometers located as shown in Figure 13. The water level remained fairly con-

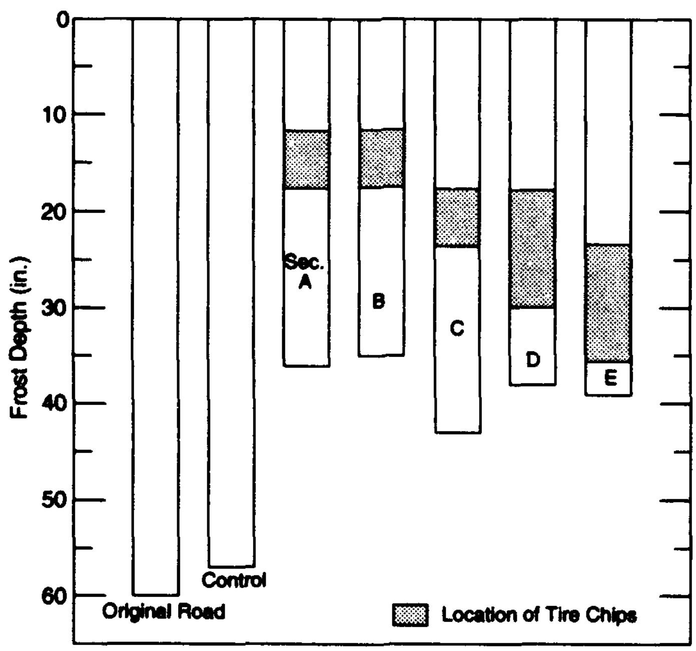

Figure 14. Maximum depth of frost penetration, 1992–1993.

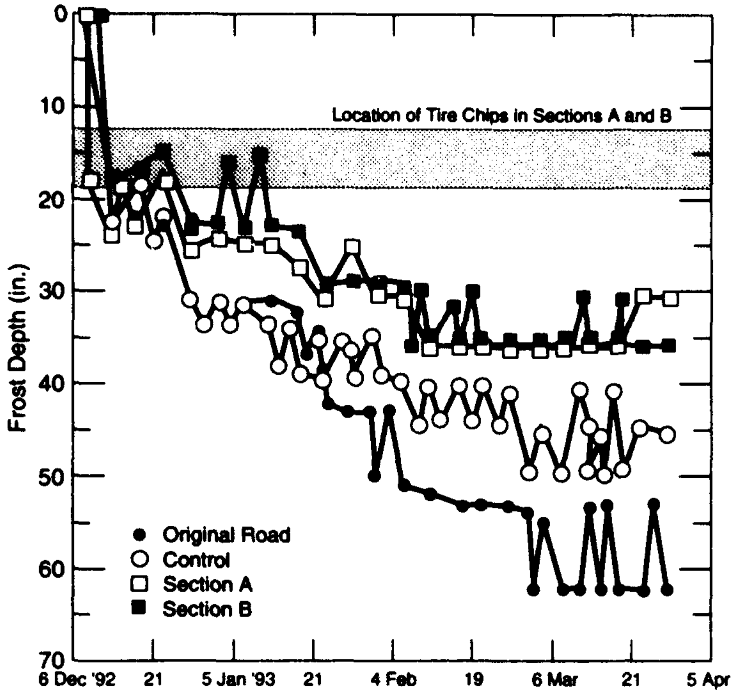

Figure 15. Depth of frost penetration versus date.

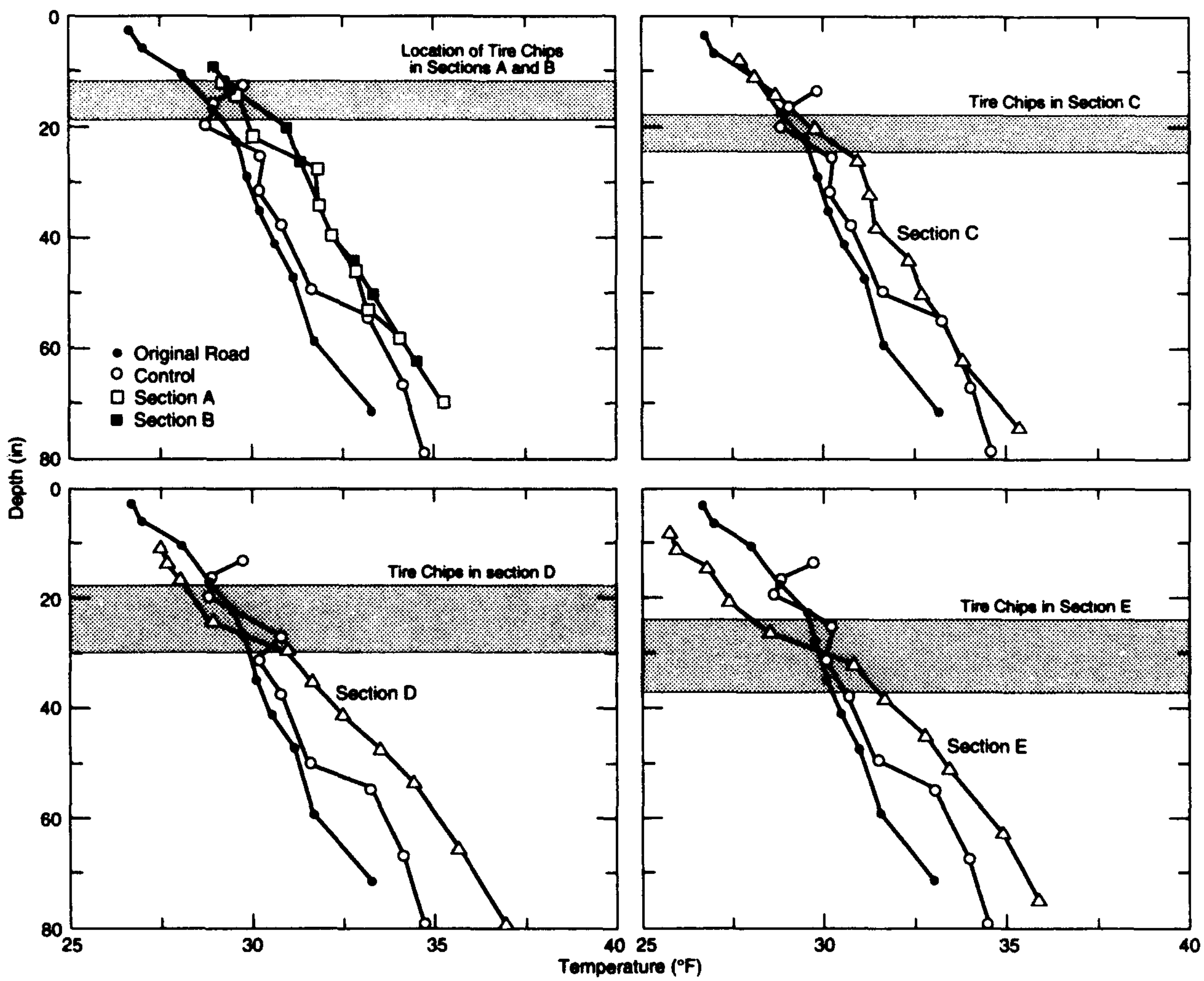

Figure 16. Temperature profile on 16 March 1993.

Table 6. Average centerline frost heave (in.).

Original road	*Control*	*Section A*	*Section B*	*Section C*	*Section D*	*Section E*	*Original road*
3.0	1.1	1.1	0.9	1.4	1.4	2.1	4.2

stant throughout the winter until thaw—on 30 March 1993, the groundwater had risen approximately 4 ft at stations 0+69, 3+00 and 3+42; 3 ft at station 6+19; to the ground surface, or 22 in., at station 6+77; and 8 in. (4 in. below the ground surface) at station 8+32. In other words, the groundwater was at or above the surface on the south side of the road at station 6+77. Three weeks later, the groundwater had dropped approximately 6 in. along the length of the road.

Surface condition survey

The condition of the test sections was measured with the Unsurfaced Road Condition Index (URCI) methodology, developed by Eaton et al. (1987). Table 8, which gives the conditions on 8 December 1992 and 21 April 1993, shows that the rubber sections B and D had developed some potholes, whereas rubber sections A, C and E basically remained unchanged. The Town had to come and regrade the original road and transitions to the rubber sections in early April because of damage from the spring thaw, but they did not touch the rubber sections because of their outstanding performance. Table 8 shows the conditions after spring regrading of everything but the rubber sections.

Surface deflections

Table 9 gives the surface deflections at selected points on each section under a 9000-lb load. Figure 18 is a plot of these data. As seen on the figure, normal period (unfrozen) deflections of all sections containing rubber are above 80 mils. The original road and control section unfrozen deflections are less than 35 mils. From December to February, when all sections were frozen, all deflections were under 5 mils.

Deflections measured with the HWD on 13 May 1993 are summarized in Figure 19. The deflections of sections A and B, which have 6 in. of tire chips overlaid with 12. in of gravel, are about 4.5 times the deflections of the original road and the control

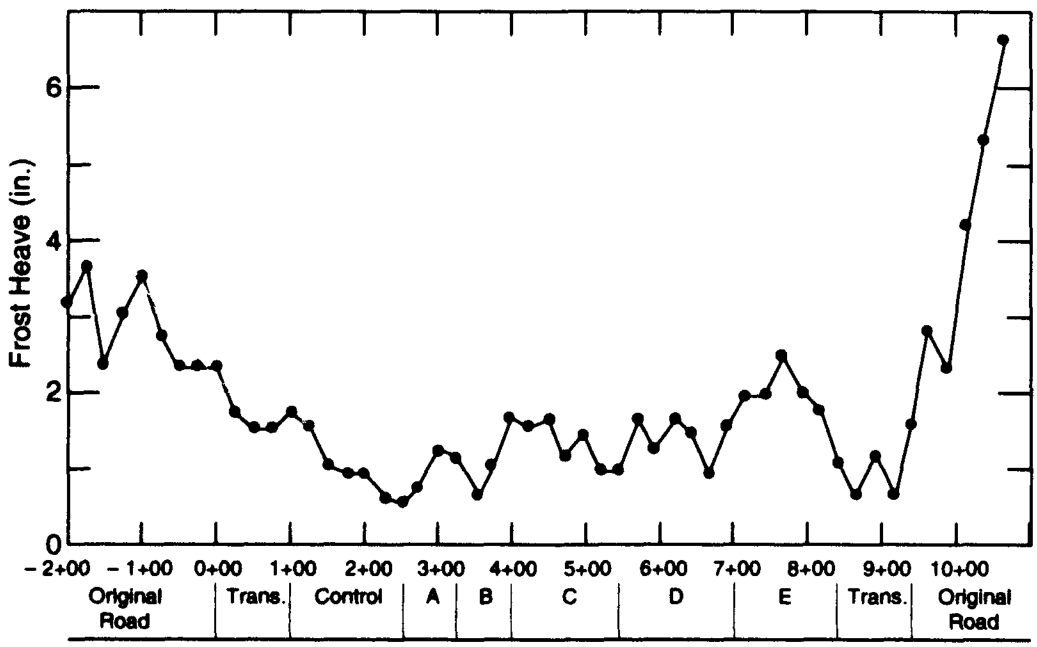

Figure 17. Centerline frost heave profile, 1992–1993.

Table 7. Groundwater elevations.

Water well	Sta.	Location*	Length of casing (ft–in.)	Top of casing	Ground elev.	Bottom of casing	1992 16 Sep	1992 6 Oct	1992 20 Oct	1992 17 Nov	1992 24 Nov	1992 14 Dec	1993 20 Jan	1993 24 Feb	1993 30 Mar	1993 21 Apr
				Elevation (ft)†												
1	0+69	18.3 left	13–8	51.44	47.44	37.77	—	—	—	38.27	38.76	40.51	40.85	40.35	44.76	44.63
2	3+00	18.3 left	13–1 1/2	47.11	42.94	33.98	—	—	—	36.02	36.45	37.62	37.95	37.95	41.95	41.44
3	3+42.5	25.5 right	13–0	46.04	42.71	33.04	33.21	33.12	33.12	35.92	37.17	37.76	37.92	33.76	42.17	42.13
												(42.91)**	(41.78)	(37.68)	—	—
4	6+19	26.5 left	22–5	43.19	39.02	20.67	—	—	—	34.00	34.68	35.85	36.43	36.68	39.85	38.98
												(40.40)	(39.48)	(39.43)	—	—
5	6+77.5	24 right	18–2	43.68	39.85	25.51	—	—	—	36.51	37.22	37.47	37.97	39.72	—	39.20
6	8+32.5	21 left	12–2	40.32	37.41	28.15	28.78	28.81	28.32	35.07	35.61	35.02	37.02	36.69	37.07	36.41

*Feet left or right of centerline of the road.
†Using assigned BM elevations.
**Depth of frost beneath center of road at that station.

Table 8. Surface condition surveys.

	Survey area*		8 Dec 1992 URCI	8 Dec 1992 Rating	21 Apr 1993 URCI	21 Apr 1993 Rating
Original road	–0+94	–1+94	70	Good	75	V. good
Transition	0+00	1+00	70	Good	72	V. good
Control	1 +00	2+50	74	V. good	80	V. good
Section A	2+50	3+25	70	Good	71	V good
Section B	3+25	4+00	70	Good	63	Good
Section C	4+00	5+50	75	V good	75	V. good
Section D	5+50	7+00	74	V. good	63	Good
Section E	7+00	8+50	71	V. good	71	V. good
Transition	8+50	9+50	67	Good	90	Excellent
Original road	10+00	11+00	44	Fair	57	Good

* Stations at either end of survey area.

Table 9. Heavyweight deflectometer measurements (plate deflection in mils, 9000-lb load).

Date	Orig. road –1+50*	Control 1+75	Section A 3+00	Section B 3+50	Section C 4+75	Section D 6+25	Section E 8+00	Orig. road 10+25
14 Sept 92	21.0	24.1	109.9	103.6	114.9	83.4	71.9	15.2
19 Oct 92	22.7	24.6	97.3	97.5	115.1	89.1	79.4	22.5
17 Nov 92	18.7	20.8	79.9	73.9	80.7	62.3	49.1	14.8
14 Dec 92	4.3	4.0	7.9	7.8	7.4	5.6	6.4	3.5
11 Jan 93	1.1	1.1	2.5	2.5	2.2	2.1	1.7	1.0
9 Feb 93	0.7	0.6	2.0	1.9	1.9	1.7	1.4	0.5
9 Mar 93	1.8	3.9	12.7	13.7	9.3	5.2	3.2	0.4
13 April 93	23.5	36.3	95.1	95.7	111.7	89.6	77.1	40.5
13 May 93	24.4	24.9	109.7	113.7	73.0	55.5	67.7	27.9

*Station.

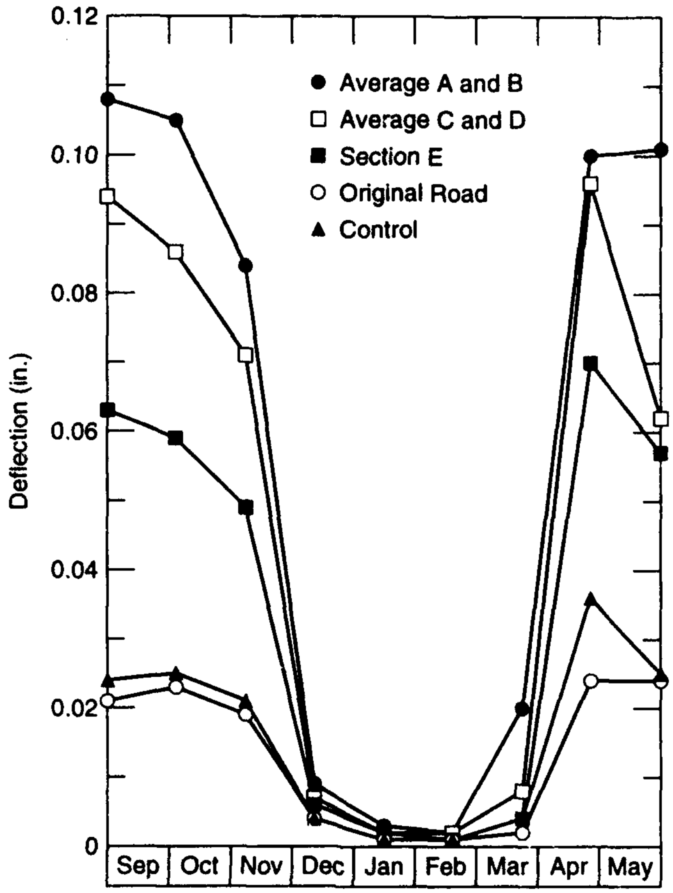

Figure 18. Plate deflections, 1992–1993.

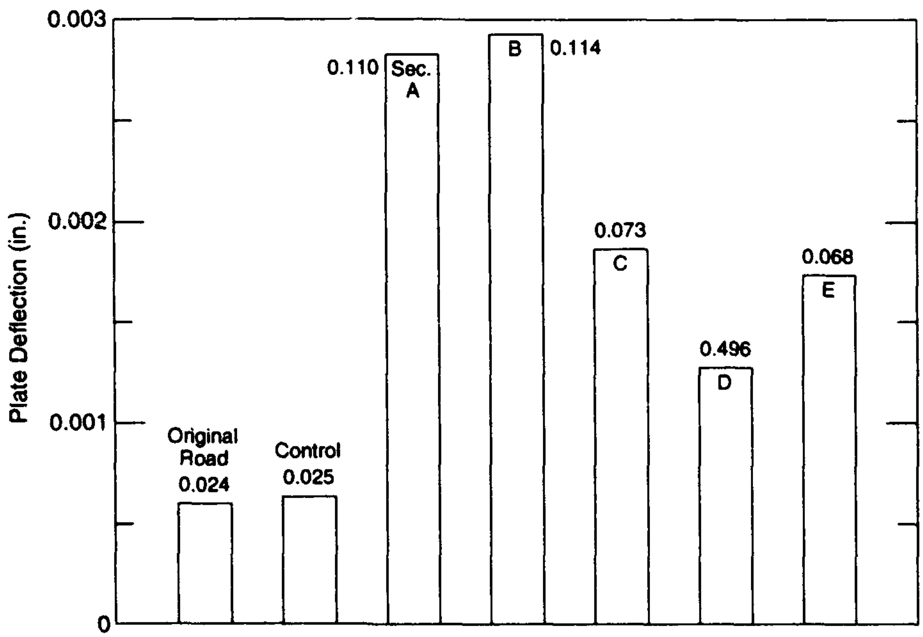

Figure 19. HWD plate deflections on 13 May 1993.

section. Increasing the cover thickness to 18 in. reduced surface deflections to 3 times the values for the original road and the control section.

The large deflections observed for the tire chip sections are not of great concern for gravel roads. However, they could be very significant for paved roads as the pavement would flex and crack unless it was thick.

Groundwater quality

No groundwater testing was conducted the first winter.

CONCLUSIONS

A full-scale field trial using tire chips as an insulating layer in a gravel surfaced road has shown that they can reduce penetration of freezing temperatures into underlying frost-susceptible soils. The first year's performance of the tire chips in an "average" winter has shown the potential of this technique to be developed into a cost-effective way to improve the trafficability of gravel-surfaced roads in cold climates during spring thaw. The feedback of town residents was very positive and they want to know when the rest of the road will be done.

Tire chips can be hauled, placed and compacted with conventional construction equipment.

As shown, there was less frost penetration beneath the rubber layers, the frost heave of the rubber sections was less than half that of the original road, and the surface conditions of the rubber sections were all better than the original road during spring thaw. Surface deflections under load decreased as the gravel cover over the rubber layers increased.

Monitoring of thermal behavior, surface support characteristics and groundwater quality will continue for the next several years.

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Humphrey, D.N. and W.P. Manion (1992) Properties of tire chips for lightweight fill. In *Grouting, Soil Improvement and Geosynthetics*. New York: American Society of Civil Engineers, pp. 1244–1355.

APPENDIX A: CONSTRUCTION PHOTOGRAPHS

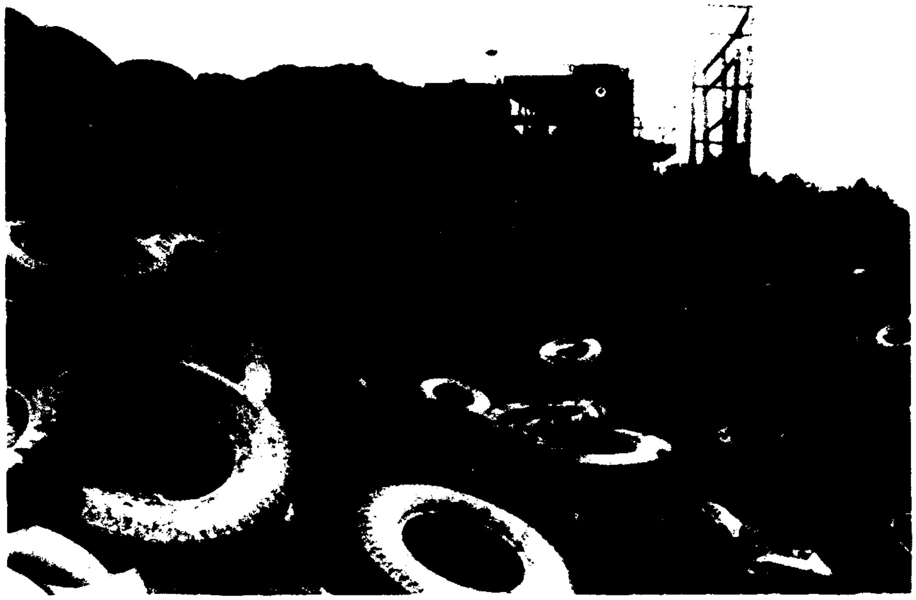

Figure A1. Stockpile of waste tires.

Figure A2. Spreading tire chips.

Figure A3. Fine grading the tire chips.

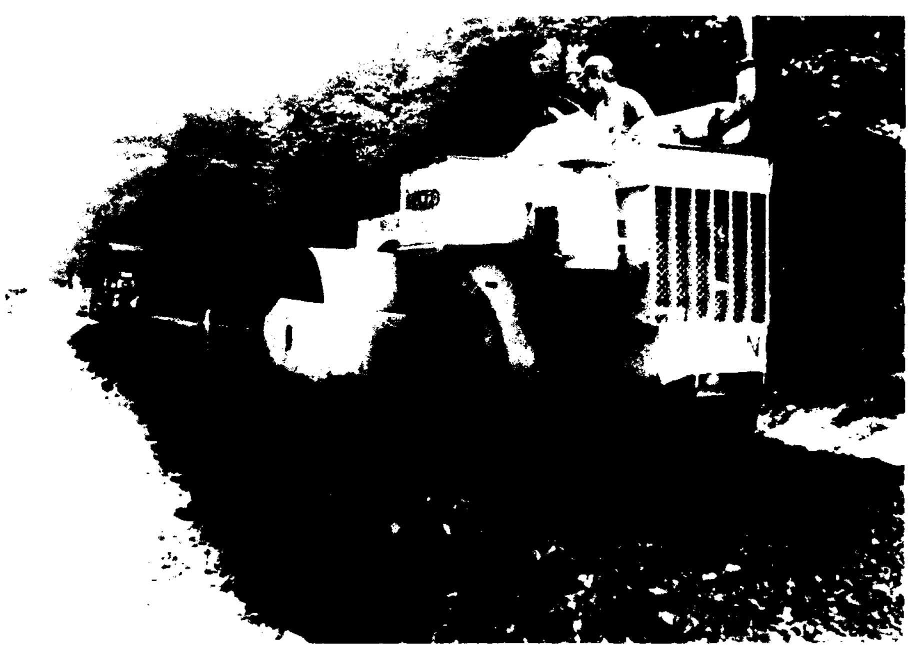

Figure A4. Using the vibratory roller to compact the chip layer.

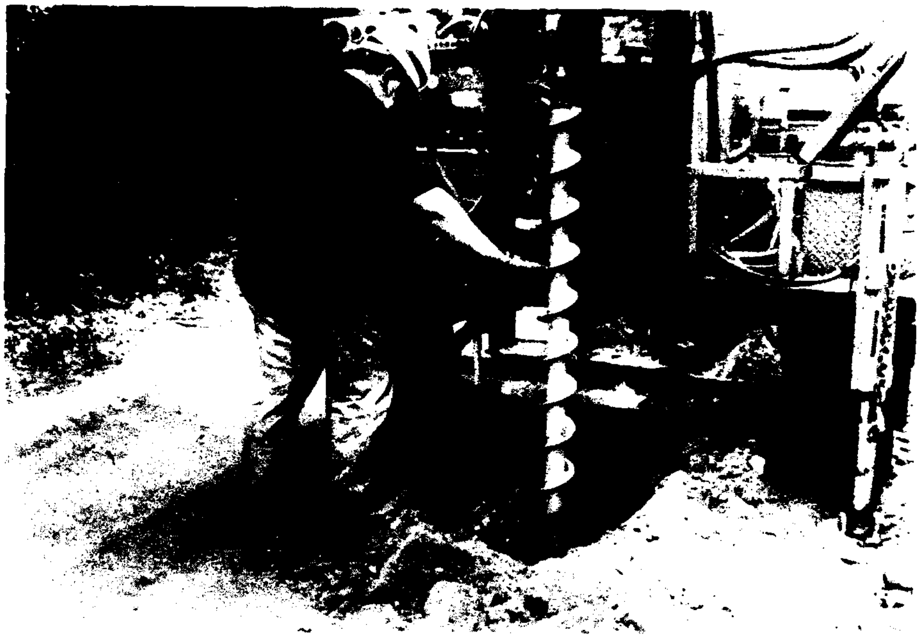

Figure A5. Drilling holes for instrumentation.

Figure A6. Compacting the soil around a thermocouple string.

Figure A7. Resistivity gauge placed in subgrade.

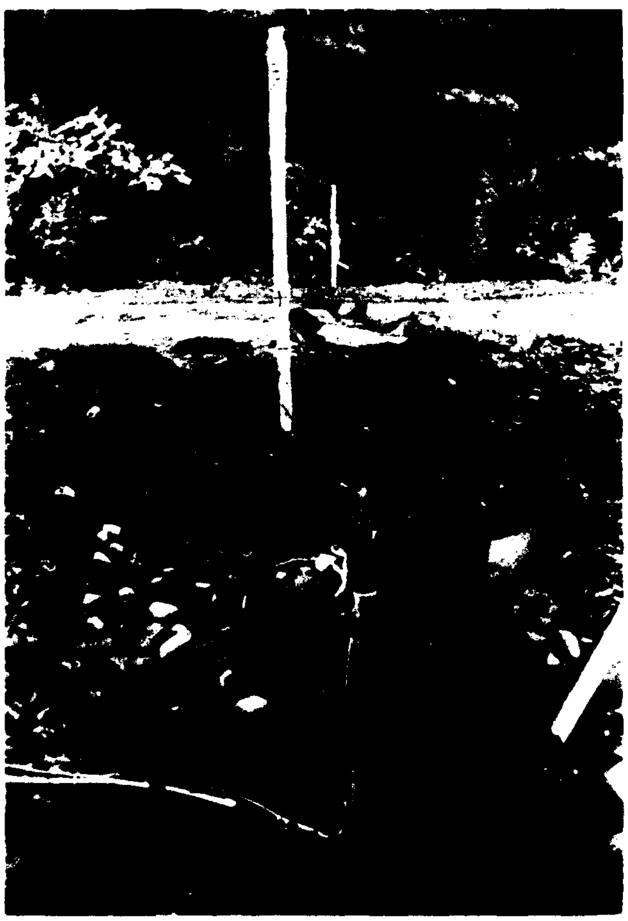

Figure A8. Thermocouple string with three fliers to be placed in overlying gravel.

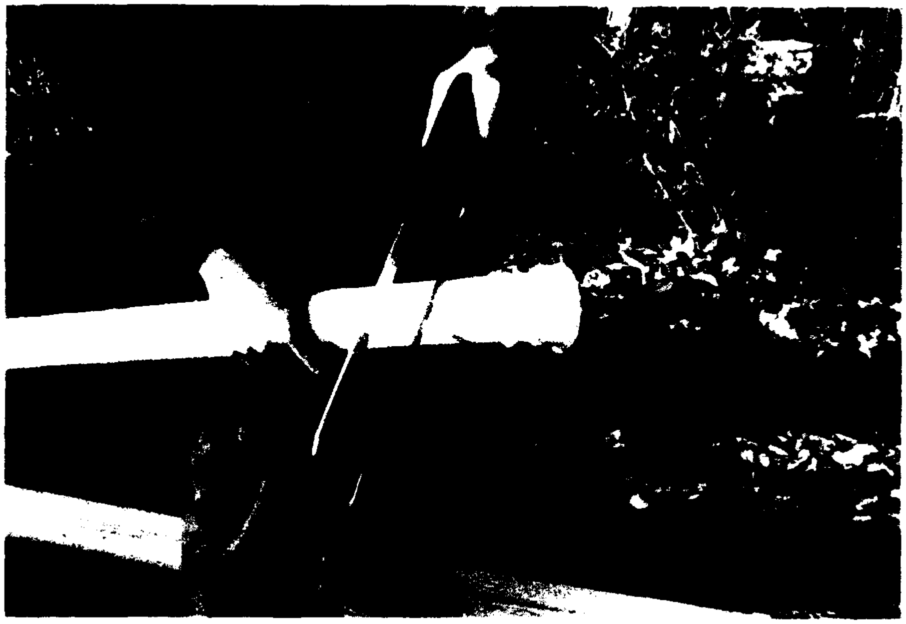

Figure A9. Cutting slots in PVC pipe for water wells.

Figure A10. Putting bentonite around water wells to seal against surface water infiltration.

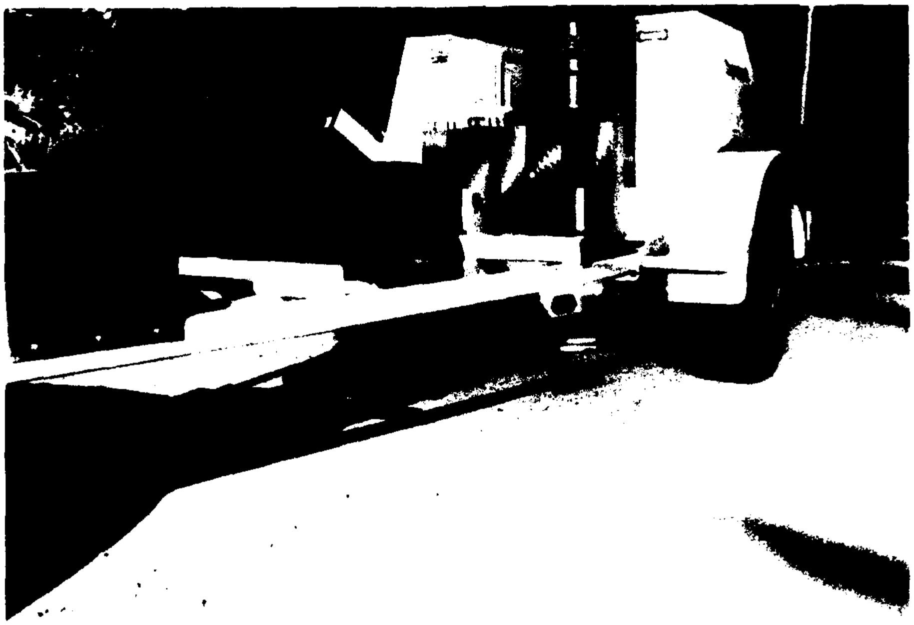

Figure A11. HWD used to measure vertical deflections after construction.

Figure A12. Surface cracks in Dingley Road.

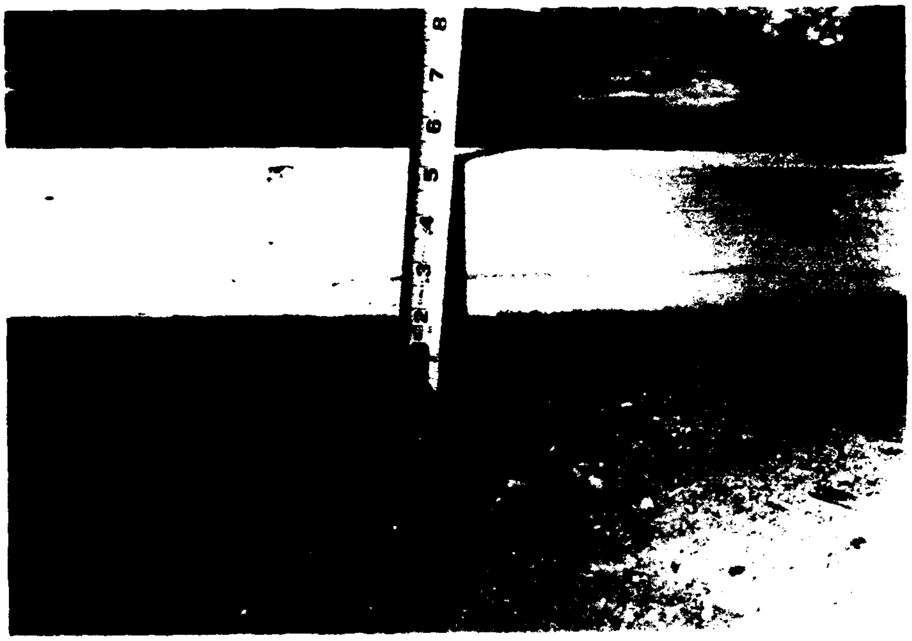

Figure A13. Rutting after one month in section A.

Figure A14. Level surveys to measure frost heave.

Figure A15. Data collection box.

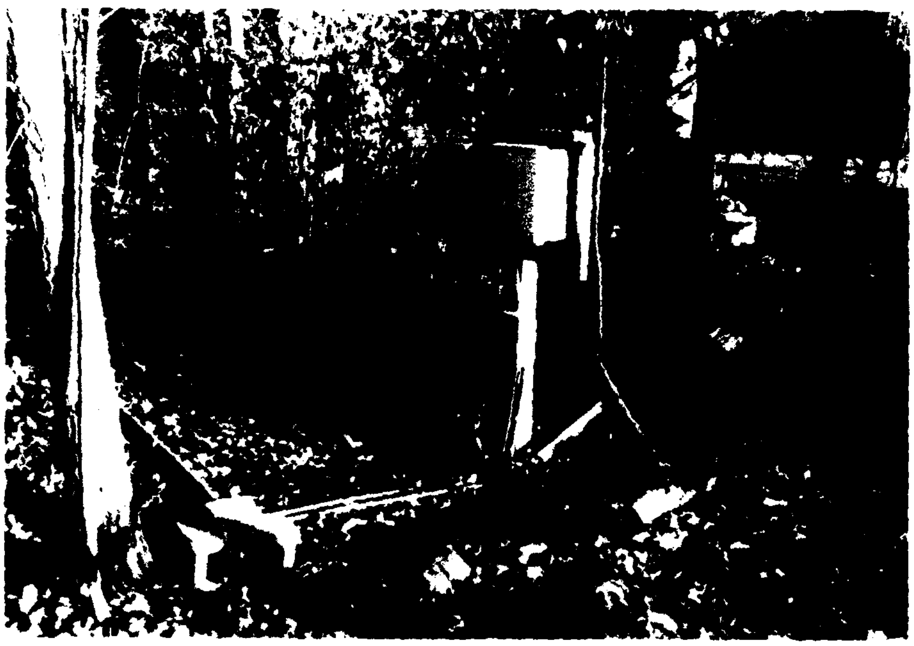

Figure A16. Data collection boxes placed in the woods, out of sight of the road.

Figure A17. Instrumentation shelter where data are collected and sent to CRREL via phone lines.

Figure A18. Normal traffic on Dingley Road does not cause noticeable surface deflection over the chips.

APPENDIX B: LOCATIONS OF THERMOCOUPLES AND RESISTIVITY GAUGES

Outside control section

Thermocouples Station –1+20 1.5 ft right of centerline			*Resistivity gauge Station –0+98 2 ft right of centerline*			*Thermocouples Station –0+78 2 ft right of centerline*		
Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)	No.	Actual elev. (ft)	Actual depth (in.)	Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)
Surface	50.60	0	Surface	50.11	0	Surface	49.90	0
3	49.95	3	1	49.35	9	3	49.65	3
6	49.70	6	2	49.18	11	6	49.40	6
12	49.33	10.5	3	49.01	13	12	48.82	13
18	48.83	16.5	4	48.85	15	18	48.32	19
24	48.33	22.5	5	48.68	17	24	47.82	25
30	47.83	28.5	6	48.51	19	30	47.32	31
36	47.33	34.5	7	48.35	21	36	46.82	37
42	46.83	40.5	8	48.18	23	42	46.32	43
48	46.33	46.5	9	48.01	25	48	45.82	49
60	45.33	58.5	10	47.85	27	60	44.82	61
72	44.33	70.5	11	47.68	29	72	43.82	73
			12	47.51	31			
			13	47.35	33			
			14	47.18	35			
			15	47.01	37			
			16	46.85	39			
			17	46.68	41			
			18	46.51	43			
			19	46.35	45			
			20	46.18	47			
			21	46.01	49			
			22	45.85	51			
			23	45.68	53			
			24	45.51	55			
			25	45.35	57			
			26	45.18	59			
			27	45.01	61			
			28	44.85	63			
			29	44.68	65			
			30	44.51	67			
			31	44.35	69			

Control section

Thermocouples Station 1+62 1.5 ft right of centerline			*Resistivity gauge Station 1+81 2 ft right of centerline*			*Thermocouples Station 1+99 2 ft right of centerline*		
Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)	No.	Actual elev. (ft)	Actual depth (in.)	Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)
Surface	46.04	0	Surface	45.74	0	Surface	45.50	0
3	44.96	13	1	43.98	21	3	44.41	13
6	44.71	16	2	43.81	23	6	44.16	16
12	44.46	19	3	43.64	25	12	43.91	19
18	43.96	25	4	43.48	27	18	43.41	25
24	43.46	31	5	43.31	29	24	42.91	31
30	42.96	37	6	43.14	31	30	42.41	37
36	42.46	43	7	42.98	33	36	41.91	43
42	41.96	49	8	42.81	35	42	41.41	49
48	41.46	54	9	42.64	37	48	40.91	54
60	40.46	66	10	42.48	39	60	39.91	66
72	39.46	78	11	42.31	41	72	38.91	78
			12	42.14	43			
			13	41.98	45			
			14	41.81	47			
			15	41.64	49			
			16	41.48	51			
			17	41.31	53			
			18	41.14	55			
			19	40.98	57			
			20	40.81	59			
			21	40.64	61			
			22	40.48	63			
			23	40.31	65			
			24	40.14	67			
			25	39.98	69			
			26	39.81	71			
			27	39.64	73			
			28	39.48	75			
			29	39.31	77			
			30	39.14	79			
			31	38.98	81			

Section A

Thermocouples Station 2+68 2 ft right of centerline			*Resistivity gauge Station 2+87 2.5 ft right of centerline*			*Thermocouples Station 3+00.5 3.5 ft right of centerline*		
Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)	No.	Actual elev. (ft)	Actual depth (in.)	Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)
Surface	44.90	0	Surface	44.80	0	Surface	44.59	0
3	43.88	12	1	42.51	27.5	3	43.68	11
6	43.55	15	2	42.34	29.5	6	43.43	14
12	43.11	21.5	3	42.17	31.5	12	43.18	17
18	42.61	27.5	4	42.01	33.5	18	42.68	23
24	42.11	33.5	5	41.84	35.5	24	42.18	29
30	41.61	39.5	6	41.67	37.5	30	41.68	35
36	41.11	45.5	7	41.51	39.5	36	41.18	41
42	40.61	51.5	8	41.34	41.5	42	40.68	47
48	40.11	57.5	9	41.17	43.5	48	40.18	53
60	39.11	69.5	10	41.01	45.5	60	39.18	65
72	38.11	81.5	11	40.84	47.5	72	38.18	77
			12	40.67	49.5			
			13	40.51	51.5			
			14	40.34	53.5			
			15	40.17	55.5			
			16	40.01	57.5			
			17	39.84	59.5			
			18	39.67	61.5			
			19	39.51	63.5			
			20	39.34	65.5			
			21	39.17	67.5			
			22	39.01	69.5			
			23	38.84	71.5			
			24	38.67	73.5			
			25	38.51	75.5			
			26	38.34	77.5			
			27	38.17	79.5			
			28	38.01	81.5			

Section B

Thermocouples Station 3+46.5 3 ft right of centerline			*Resistivity gauge Station 3+62.5 2.5 ft right of centerline*			*Thermocouples Station 3+74.5 3 ft right of centerline*		
Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)	No.	Actual elev. (ft)	Actual depth (in.)	Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)
Surface	44.12	0	Surface	43.98	0	Surface	43.90	0
3	43.33	9.5	1	42.18	21.5	3	43.19	8.5
6	43.08	12.5	2	42.01	23.5	6	42.94	11.5
12	42.83	14	3	41.84	25.5	12	42.69	14.5
18	42.33	20	4	41.68	27.5	18	42.19	20.5
24	41.83	26	5	41.51	29.5	24	41.69	26.5
30	41.33	32	6	41.34	31.5	30	41.19	32.5
36	40.83	38	7	41.18	33.5	36	40.69	38.5
42	40.33	44	8	41.01	35.5	42	40.19	44.5
48	39.83	50	9	40.84	37.5	48	39.69	50.5
60	38.83	62	10	40.68	39.5	60	38.69	62.5
72	37.83	74	11	40.51	41.5	72	37.69	74.5
			12	40.34	43.5			
			13	40.18	45.5			
			14	40.01	47.5			
			15	39.84	49.5			
			16	39.68	51.5			
			17	39.51	53.5			
			18	39.34	55.5			
			19	39.18	57.5			
			20	39.01	59.5			
			21	38.84	61.5			
			22	38.68	63.5			
			23	38.51	65.5			
			24	38.34	67.5			
			25	38.18	69.5			
			26	38.01	71.5			
			27	37.84	73.5			
			28	37.68	75.5			

Section C

Thermocouples Station 4+50 3 ft right of centerline			*Resistivity gauge Station 4+80.5 2.5 ft right of centerline*			*Thermocouples Station 5+04 2 ft right of centerline*		
Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)	No.	Actual elev. (ft)	Actual depth (in.)	Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)
Surface	43.52	0	Surface	43.28	0	Surface	43.13	0
3	42.88	7.5	1	41.15	25.5	3	42.34	9.5
6	42.63	10.5	2	40.98	27.5	6	42.09	12.5
12	42.38	13.5	3	40.81	29.5	12	41.84	15.5
18	41.88	19.5	4	40.65	31.5	18	41.34	21.5
24	41.38	25.5	5	40.48	33.5	24	40.84	27.5
30	40.88	31.5	6	40.31	35.5	30	40.34	33.5
36	40.38	37.5	7	40.15	37.5	36	39.84	39.5
42	39.88	43.5	8	39.98	39.5	42	39.34	45.5
48	39.38	49.5	9	39.81	41.5	48	38.84	51.5
60	38.38	61.5	10	39.65	43.5	60	37.84	63.5
72	37.38	73.5	11	39.48	45.5	72	36.84	75.5
			12	39.31	47.5			
			13	39.15	49.5			
			14	38.98	51.5			
			15	38.81	53.5			
			16	38.65	55.5			
			17	38.48	57.5			
			18	38.31	59.5			
			19	38.15	61.5			
			20	37.98	63.5			
			21	37.81	65.5			
			22	37.65	67.5			
			23	37.48	69.5			
			24	37.31	71.5			
			25	37.15	73.5			

Section D

Thermocouples
Station 6+04
2.5 ft right of centerline

Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)
Surface	42.57	0
3	41.64	11
6	41.30	14
12	41.14	17
18	40.64	23
24	40.14	29
30	39.64	35
36	39.14	41
42	38.64	47
48	38.14	53
60	37.14	65
72	36.14	77

Resistivity gauge
Station 6+24
2 ft right of centerline

No.	Actual elev. (ft)	Actual depth (in.)
Surface	42.37	0
1	39.70	32
2	39.53	34
3	39.36	36
4	39.20	38
5	39.03	40
6	38.86	42
7	38.70	44
8	38.53	46
9	38.36	48
10	38.20	50
11	38.03	52
12	37.86	54
13	37.70	56
14	37.53	58
15	37.36	60
16	37.20	62
17	37.03	64
18	36.86	66
19	36.70	68
20	36.53	70
21	36.36	72
22	36.20	74

Thermocouples
Station 6+47
3 ft right of centerline

Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)
Surface	42.17	0
3	41.37	9.5
6	41.12	12.5
12	40.87	15.5
18	40.37	21.5
24	39.87	27.5
30	39.37	33.5
36	38.87	39.5
42	38.37	45.5
48	37.87	51.5
60	36.87	63.5
72	35.87	75.5

Section E

Thermocouples Station 7+56 4 ft right of centerline			*Resisitivity gauge Station 7+71 5 ft right of centerline*			*Thermocouples Station 8+00 5 ft right of centerline*		
Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)	No.	Actual elev. (ft)	Actual depth (in.)	Proposed depth (in.)	Actual elev. (ft)	Actual depth (in.)
Surface	41.25	0	Surface	41.07	0	Surface	40.92	0
3	40.59	8	1	37.99	37	3	40.32	7
6	40.34	11	2	37.82	39	6	40.07	10
12	40.09	14	3	37.65	41	12	39.82	13
18	39.59	20	4	37.49	43	18	39.32	19
24	39.09	26	5	37.32	45	24	38.82	25
30	38.59	32	6	37.15	47	30	38.32	31
36	38.09	38	7	36.99	49	36	37.82	37
42	37.59	44	8	36.82	51	42	37.32	43
48	37.09	50	9	36.65	53	48	36.82	49
60	36.09	62	10	36.49	55	60	35.82	61
72	35.09	74	11	36.32	57	72	34.82	73
			12	36.15	59			
			13	35.99	61			
			14	35.82	63			
			15	35.65	65			
			16	35.49	67			
			17	35.32	69			
			18	35.15	71			

APPENDIX C: HEAVYWEIGHT DEFLECTOMETER TEST POINTS

Right wheel track heading southeast	Right wheel track heading northwest
−2+00	10+85
−1+75	10+60
−1+50	10+35
−1+25	10+10
−1+00	8+35
−0+75	8+10
−0+50	7+85
−0+25	7+60
1+25	7+35
1+50	7+10
1+75	6+85
2+00	6+60
2+25	6+35
2+75	6+10
3+00	5+85
3+50	5+60
3+75	5+35
4+25	5+10
4+50	4+85
4+75	4+60
5+00	4+35
5+25	4+10
5+75	3+85
6+00	3+60
6+25	3+35
6+50	3+10
6+75	2+85
7+25	2+60
7+50	2+35
7+75	2+10
8+00	1+85
8+25	1+60
10+00	1+35
10+25	1+10
10+50	−0+15
10+75	−0+40
	−0+65
	−0+90
	−1+15
	−1+40
	−1+65
	−1+90

APPENDIX D: LEVEL SURVEY POINTS

Point	*Station*	*Location*
Temporary benchmarks (telephone poles—nail in side)		
TBM 1	-0+94	17.8 ft right of centerline
TBM 2	2+55	24.4 ft right of centerline
TBM 3	5+90	27.4 ft right of centerline
TBM 4	9+44	23.3 ft right of centerline
Frost-free benchmarks		
BM 1	3+85.5	22.7 ft right of centerline
BM 2	8+27.5	21.5 ft left of centerline
Culvert 16-in. diameter		
Culvert	9+03.5	Southwest end (right side) Northeast end (left side)
Road		
Survey points in left and right wheel tracks and on centerline starting at station –2+00 every 25 ft to station 10+75.		

APPENDIX E: WATER WELL DESCRIPTIONS

Water well	*Station*	*Location from centerline (ft)*	*Length of casing (ft-in.)*	*Top of casing*	*Ground elevation*	*Bottom of casing*
1	0+69	18.3 left	13-8	51.44	47.44	37.77
2	3+00	18.3 left	13-1 1/2	47.11	42.94	33.98
3	3+42.5	25.5 right	13-0	46.04	42.71	33.04
4	6+19	26.5 left	22-5	43.19	39.02	20.67
5	6+77.5	24 right	18-2	43.68	39.85	25.51
6	8+32.5	21 left	12-2	40.32	37.41	28.15

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 1994	

4. TITLE AND SUBTITLE
Gravel Road Test Sections Insulated with Scrap Tire Chips: Construction and First Year's Results

5. FUNDING NUMBERS

6. AUTHORS
Robert A. Eaton, Richard J. Roberts and Dana N. Humphrey

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, N.H. 03755-1290

8. PERFORMING ORGANIZATION REPORT NUMBER
Special Report 94-21

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of the Chief of Engineers
Washington, D.C. 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.
Available from NTIS, Springfield, Virginia 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

A test project that uses tire chips as an insulating layer to limit frost penetration beneath a gravel-surfaced road is described. Tire chips, which are waste tires that have been cut into 2-in. pieces, are an attractive alternative to conventional insulation boards because they have moderate thermal resistance and are durable, free-draining and low cost. Furthermore, this application has the potential to make an important contribution to disposing of the more than 2 billion waste tires that are currently sitting in huge open piles across the U.S. The project was constructed in Richmond, Maine, in August 1992. It is 750 ft long, consisting of five sections with different thicknesses of tire chips and overlying soil cover and two control sections. Over 20,000 waste tires were used on this project. The primary goals were to determine the necessary thickness of tire chips to provide effective insulation and the minimum thickness of overlying soil cover needed to produce a stable riding surface. The thickness of the tire chip layers ranges from 6 to 12 in., while the thickness of the granular soil cover ranges from 12 to 24 in. The project is instrumented with thermocouples, resistivity gauges, groundwater monitoring wells and a weather station. In addition, the strength of the road surface is periodically measured with a heavy weight deflectometer. Results from the first year of service have shown that a 6-in. tire chip layer can reduce frost penetration by up to 25% and the gravel cover should be 12 to 18 in. thick to provide a stable riding surface.

14. SUBJECT TERMS

Cold Regions	Gravel roads	Rubber chips in roads
Frost heave	Insulated gravel roads	Scrap tire chips in roads

15. NUMBER OF PAGES
52

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL